15th IranianHydraulic Conference, 14-15 December 2016
Faculty of Engineering and Technology, Imam Khomeini International University,
Qazvin, Iran

Study of Circulation NumberFluctuationsinPapaya Spillway

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Abstract

Papaya spillway, mixing the piano key weir principles on a shaft spillway was tested in this research. Overall 80 experiments were conducted using physical models. Three models of papaya spillway with different angles were tested and experiments data were analyzed. This paper is devoted to explain about effects of using piano key inlet on shaft spillway on circulation number. Comparison between three papaya models showed that papaya model with an angle of 90 degrees has minor circulation number so that it has minor circulation strength compare with other models. As a result, it can pass higher amount of discharge through the shaft. In other words, papaya model with an angle of 90 degrees has better performance beyond comparison.

Keywords:Papaya Spillway,Shaft Spillway, Piano-Key Weir, Circulation number

15Hydro-609

1. INTRODUCTION

A new shape of free-flow spillway (the “Piano Key weir”) can increase the specific flow fourfold or more. It could substantially reduce the cost of most new dams and increase, at low cost, the safety and the storage and/or the flood control efficiency of many existing dams.Preliminary model tests were done in 1999 at the LNH Laboratory in France (owned by Electricité de France) and in 2002 at Roorke University in India and Biskra University in Algeria [1].

This new type of weir characterized by:

- A simple geometrical configuration which allows the use of the prefabricated units,
- An operation similar at the weirs with free flow but much more effective,
- Multiply at least by four the specific flow of a standard weir,
- Reduced considerably the cost of the majority of the new dams and guaranteed their safety [2].

Various configurations of Piano Key weirs set on a morning glory spillway have been studied on hydraulic models at LNH hydraulic laboratory. They allow for morning glory spillways, as for straight crested spillways, to reduce the required head of water and thus to maximize the increase in storage capacity, in case the hydraulic performances of the spillway are to be upgraded (re-evaluation of the design flood for instance). An innovative solution based upon PK weir principle better shares the flow between the central part of the shaft and the external part. Findings are rewarding, as even for high flows, the discharge is very stable without any vortex. The optimization can be done on hydraulic for any specific project [3]. This innovative solution is called PAPAYA spillway.

Papaya spillway, mixing the PK weir principles on a morning glory spillway was tested on a 1/20 scale model of the Bage dam, and the hydraulic performances were compared to the results of the current morning glory spillway. With a lower diameter, the Papaya spillway showed better hydraulic performances than the traditional morning glory. The central water supply of the shaft avoid the risks of vortex formation and of air entrainment and the spillway can operate at higher discharges without being submerged. The Papaya spillway increases the release capacity especially at low heads where it can be four times higher than a traditional morning glory of the same diameter. The improvement of the release capacity decreases with the head but remains greater than 30% [4].

In 2010s, one of Scottish Water’s most ambitious projects has been started to raise the height of the Black Esk dam and increase the reservoir’s storage capacity and improve the security of the water supply. Significant research took place to identify the most effective solution for Black Esk. One major challenge was that the overflow for the reservoir, which needed to be raised along with the dam, represented a significant engineering hurdle. Its bell-mouth spillway is an unusual 12-sided design and is of 56ft mean diameter at crest level. At the end, a circular piano key configuration that will be mounted atop the existing bell mouth spillway has been proposed [5].

The overflow level is being raised, increasing the storage volume about 40%, by the innovative adoption of precast piano key (PK) weirs around the rim of the bell mouth. The initial hydraulic design was undertaken by adapting published empirical relationships and then refined using computational fluid dynamics (CFD) analyses. For circular piano key inlet design, two configurations have been considered; 12 and 24 cycle weirs. Unfortunately, 24-cycle design gave slightly poorer hydraulic performance than the 12-cycle design, but were nevertheless favored because they would be small enough to allow prefabrication of individual units, as well as offering a smaller external overhang which would be helpful during construction [6].

Experiments and investigations were conducted on laboratory models showed that by using circular piano key inlet on shaft spillway, considerable alteration will be occurred on hydraulic performance. It leads to increasing shaft discharge capacity and reducing head of water on spillway. Comparison between PK inlets with 0.2 and 0.15m length showed that increasing length of PK inlet leads to better hydraulic performance because not only it leads to increasing discharge flow but also it leads to reducing the core vortex turbulence. Also, comparison between models with different angles showed that PK inlet with an angle of 90 degrees has better performance [7].

Considering that laboratory modeling is time consuming and costs more, Nasiri et al have studied hydraulic flow in shaft spillway with piano key inlet using Fluent software. Governing equations including Continuity equation and Navier-Stokes equation were solved using finite volume method and flow field on spillway was simulated numerically. Using piano key inlet leads to increasing shaft spillway discharge considerably, the study showed. Also, by increasingdischarge, vortex strength and flow circulation increase so that role of piano key inlet as a vortex breaker will be highlighted [8].

In this study, some laboratory experiments were conducted on papaya spillway models with 3 different angles and effects of using piano key inlet on shaft spillway were analyzed. This paper is devoted to explain the fluctuations of circulation number in different papaya models.

2. Material and Methods

This research was conducted in hydraulic laboratory of water engineering department, college of agriculture, Bu-Ali SinaUniversity, Hamadan, Iran. The experiments have carried out in hydraulic flume with dimensions of 10m, 0.83m and 0.5m, length, width and height respectively. Hydraulic flume is made of glass with 1 cm thick to make flow observation much easier. To decelerate water which flows through a centrifuge pump, we used wave suppressor in the inlet of flume as it is shown in Figure 1.

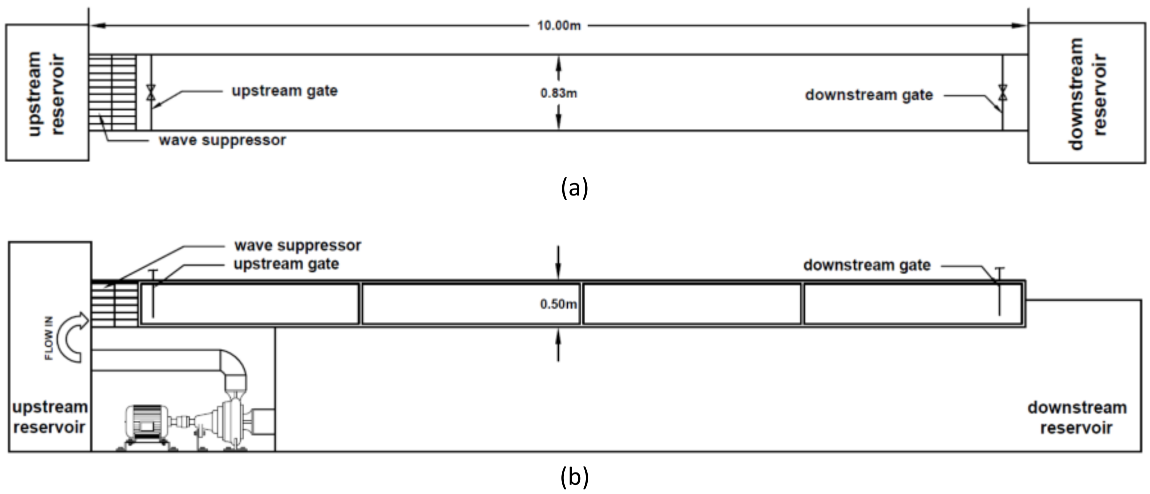
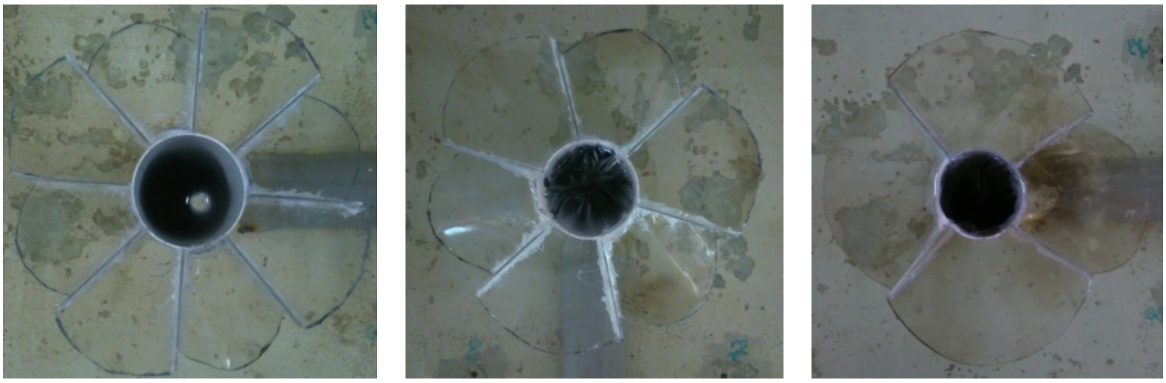


Figure 1. (a) plan, (b) front view of laboratory flume

All experiments have been carried out in the laboratory flume using physical models. Acrylic sheets were used for making physical models of papaya spillway to make the observation of flow and air entrainment inside the models possible. Dimension of models were selected by considering the dimension of flume due to avoiding vortex formation near the flume's walls. Besides thickness of acrylic sheets was selected according to make sure that model's weight would be appropriate to put it on vertical shaft. Three models of papaya spillway with different angles were made and they are shown in Figure 2.



α =45 α =60 α =90

Figure 2. Physical models of papaya spillway with different angles

Each model has been installed on vertical shaft which was located in laboratory flume. After measuring some hydraulic parameters including discharge and head, the model would be removed from vertical shaft and the next one would be installed. An ultrasonic flowmeter has been used for measuring discharge and a point gage with ±1 mm accuracy has been used for measuring head of water. Schematic shape of model and vertical shaft and their dimensions are illustrated in Figure 3.

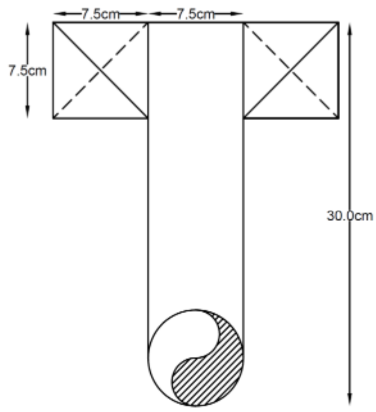


Figure 3. Schematic shape of papaya spillway model

For calculating Circulation Number, some equations were used and they are described as follow:

$$N_\Gamma = \frac{\Gamma D}{Q} \quad (1)$$

Where N_Γ is circulation number, Γ, D and Q are circulation strength, diameter and discharge, respectively.

$$\Gamma = 2\pi r^2 \omega \quad (2)$$

Where r is distance from center of vortex and ω is angular velocity which can be calculated as below, by considering H as head of water on the papaya model.

$$Q = H\omega^2 \, r^2/2$$

(3)

3. Results and Discussion

In this research, overall 80 experiments were conducted on 3 physical models in hydraulic laboratory. Data of laboratory experiments were analyzed and the result would be shown in some graphs as below. In these graphs, non-dimensional number of circulation is shown versus non-dimensional ratio of H/D.

Graph of N_Γ versus H/D for papaya spillway model with an angle of 45 degrees is illustrated in Figure 4. As it is shown in the graph by increasing N_Γ, H/D ratio will be decreased. Circulation number is related with discharge inversely which means by discharge increase, circulation number decrease. Although by discharge increase, angular velocity and therefore circulation would be increased, the effect of discharge increase is predominate. Γ which used in these graphs is average circulation in distance of 20 cm from central shaft due to the fact that in this area free vortex occurs and circulation is approximately constant.Also, graphs for papaya spillway with angles of 60 and 90 degrees is illustrated in Figure 5 and Figure 6,respectively.

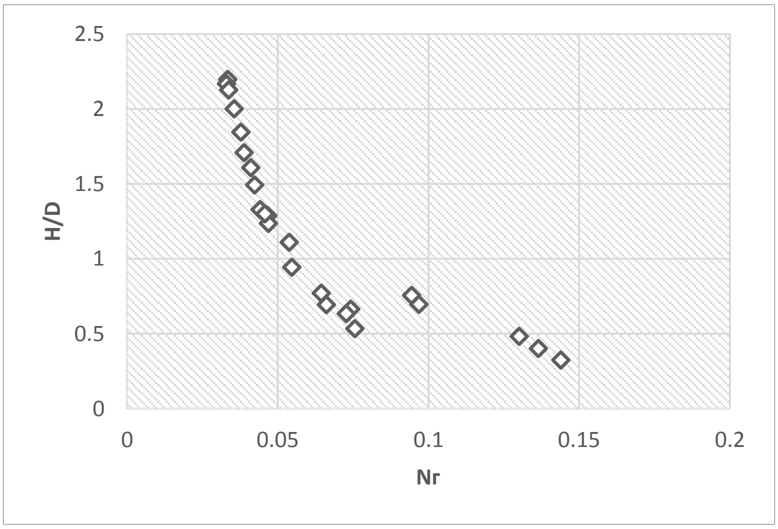


Figure 4. Circulation number vs. H/D, papaya spillway model with an angle of 45 degrees

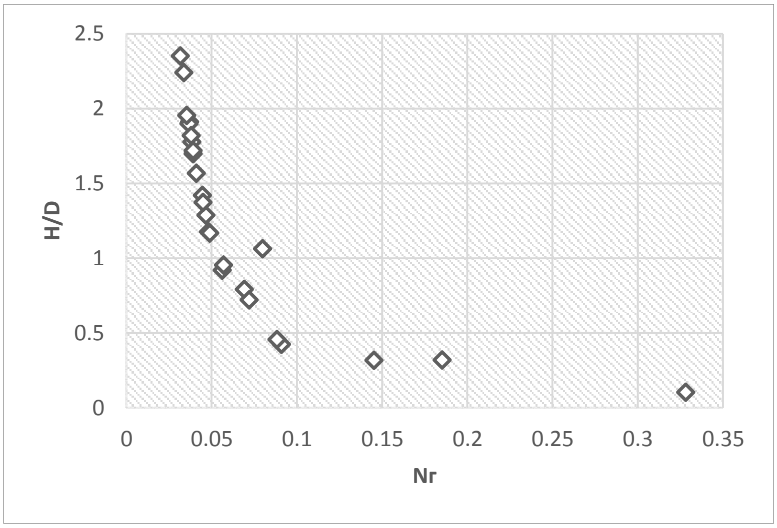


Figure 5. Circulation number vs. H/D, papaya spillway model with an angle of 60 degrees

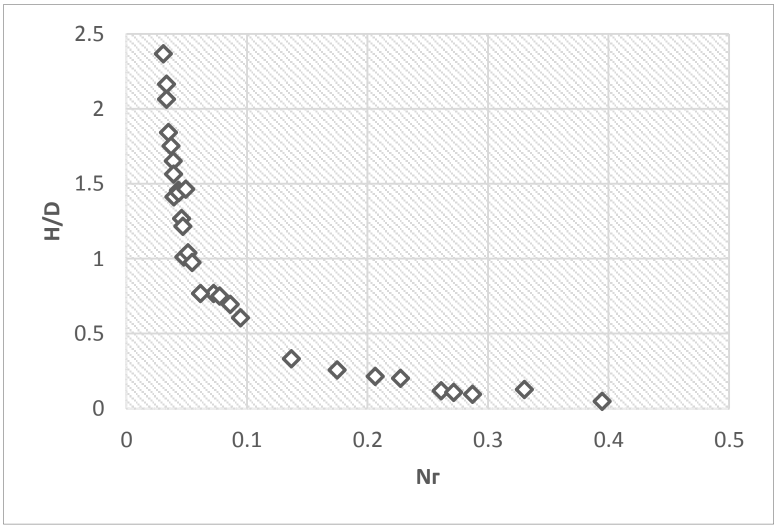


Figure 6. Circulation number vs. H/D, papaya spillway model with an angle of 90 degrees

Comparison between graphs of circulation number versus H/D for all papaya models is illustrated in Figure 7. As it is shown, for a constant circulation number, amount of H/D ratio is less in papaya spillway models by angles of 90, 45 and 60 degrees, respectively.

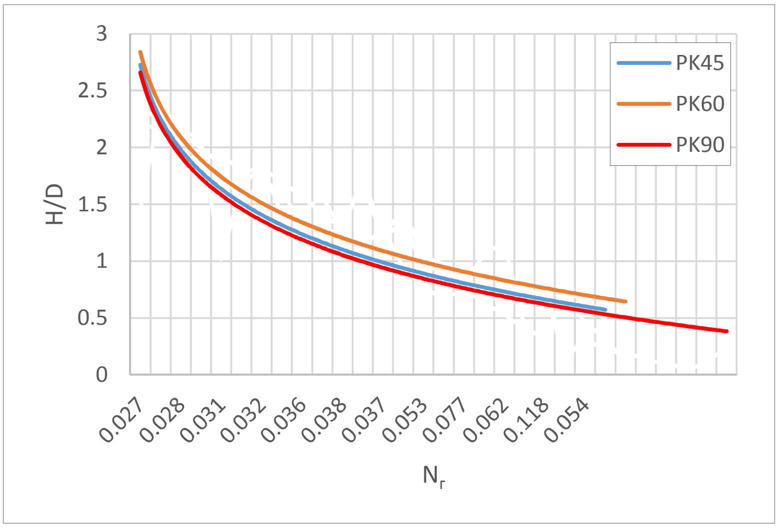


Figure 7. N_{Γ} vs. ratio of H/D, comparison between papaya models with different angles

4. CONCLUSIONS

Overall 80 experiments were conducted on papaya spillway, an innovative solution based upon piano key weir principles, using physical models in hydraulic laboratory. Hydraulic parameters were measured on 3 papaya models with different angles. Data were analyzed and circulation number for each model were measured.

Circulation number is related with discharge inversely which means by discharge increase, circulation number decrease. Although by discharge increase, angular velocity and therefore circulation would be increased, the effect of discharge increase is predominate. H/D ratio has been decreased by increasing circulation number (N_{Γ}), experiments results showed. Comparison between 3 papaya models showed that for a constant amount of circulation number, amount of non-dimensional ratio of H/D is less in papaya spillway models by angles of 90, 45 and 60 degrees, respectively. Papaya model with angle of 90 degrees has minor circulation number so that it has minor circulation strength (Γ) compare with other models.As a result, it can pass higher amount of discharge through the shaft. In other words, papaya model with an angle of 90 degrees has better performance beyond comparison.

5. ACKNOWLEDGMENT

Authors would like to express their gratitude to Eng. Ehsan Olyaie for his valuable supports and precious guides during this research.

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